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Chapter

The Field of Cardiac Electrophysiology

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Abstract

Cardiac electrophysiology is a unique and growing field that has made numerous advances in the past 15 years. Specifically, the field is advancing in terms of types of procedures as well as scope of practice. Pacemakers, implantable cardioverter-defibrillators (ICDs), and ablations have been the cornerstone of the field and continue to treat more and more conditions. This chapter will convey a birds-eye view of the types of the procedures in electrophysiology, the indications/contraindications, and the advances in the past 15 years. Additionally, local vs. general anesthesia in these procedures as well as the indication for the type of anesthesia will be discussed. The overall aim of this chapter is to present a unique viewpoint of cardiac electrophysiology as well as elaborate on the various types of anesthesia in this field.

Keywords: pacemaker, implanted cardioverter defibrillator, ablation, atrial fibrillation, electrophysiology

1. Introduction

Over 50 years ago, the cardiac action potential was first applied to clinical medicine [1]. This action potential includes four separate phases: resting, rapid depolarization, rapid repolarization, and a plateau phase with each of these phases correlating to a different ion channel as well as a different physiologic event in the heart [2]. The field of cardiac electrophysiology addresses and treats inherent faults within the heart’s action potential as well as structural causes of cardiac arrhythmias. Historically, arrhythmias were classified into three distinct categories: abnormal impulse generation, abnormal impulse conduction, simultaneous impulse generation/conduction [3]. Although the types of arrhythmias could be distinguished, all abnormal rhythm pathophysiology were found to consistently be related to an abnormal action potential. For example, in 1991 a study was performed proving that the action potential is prolonged in hypertrophied hearts signifying the relationship between the action potential and damaged tissue [4]. Furthermore in cardiomyopathy, K+ channels have been shown to be altered also prolonging the cardiac action potential [5]. Finally in long QT syndrome a link to a specific gene affecting a specific ion channel was identified affecting the action potential and thus demonstrating that arrhythmias
can occur in structurally normal hearts if there is an abnormality in the cell’s ion channels [6].

The relationship between ion channel/action potential abnormality and related cardiac structure is the foundation of cardiac electrophysiology. Pharmacology, procedures, and patient care have come from this relationship. As intensive research has been performed since the original thesis of ion channels and arrhythmias, advances in the field have grown at an extremely rapid rate. Pacemakers (transcutaneous and permanent), catheter-based ablations for all type of arrhythmias, cardioversions, and non-invasive cardiac monitoring have become the new norm in electrophysiology. Additionally, advances in anesthesiology have allowed shorter procedure times, more efficient procedures, and less risk. This chapter will highlight some of the most important procedures, indications for these procedures, current advances, and the role anesthesiology plays in cardiac electrophysiology.

2. The most common procedures of cardiac electrophysiology

2.1 Catheter ablations

In 1886, Walter Gaskell discovered specialized muscle fibers between the atria and the ventricle caused an irregular rhythm when cut—which was the first indication of an electrical system within the heart [7]. This has since become the basis of procedures such as cardiac or catheter ablations in electrophysiology. Presently, catheter ablations are used for almost every type of cardiac arrhythmia including: paroxysmal supraventricular tachycardia (SVT), atrial fibrillation, atrial flutter, and ventricular arrhythmias including frequent premature ventricular contractions and ventricular tachycardia.

2.1.1 Atrial fibrillation

Atrial fibrillation is the most common cardiac arrhythmia in clinical practice with 6–12 million people predicted to suffer from this condition in the United States by 2050 [8]. The condition stems from ectopic beats typically from the pulmonary veins causing the atria to rapidly contract [9]. This arrhythmia can lead to a multitude of complications including adverse remodeling as well as increased stroke risk from clot formation in stagnant blood. Atrial fibrillation is divided into three types: paroxysmal (lasting less than 7 days and self-terminating), persistent (longer than 7 days), and permanent (where there is decision to make no attempt at restoration of sinus rhythm). Typically, rapidly acting anti-arrhythmic agents especially amiodarone are first-line treatment for paroxysmal atrial fibrillation to attempt conversion. Cardioversion, an electric shock sent through the heart to reset the electrical circuit, is second line if pharmaceuticals do not work. Finally, since 85–95% of patients have their atrial fibrillation stemming from pulmonary veins, ablating these specific spots can be quite successful [10]. Treatment success rate of ablations for paroxysmal atrial fibrillation is between 65 and 75% [11]. Unfortunately, persistent atrial fibrillation is much less successful with a procedure success rate of roughly 45% [12]. Regardless, ablation therapy can be an effective treatment for atrial fibrillation particularly when combined with an anti-arrhythmic agent. A short procedure over continuous medical management can be beneficial to young and healthy individuals with a new diagnosis as well as the older population to avoid an overuse of medication.
The goal of atrial fibrillation ablation is to ablate or burn the connection between the pulmonary veins and the left atrium, often referred to as pulmonary vein isolation (PVI). The type of anesthesia during the procedure has also shown specific benefits. General anesthesia is preferred to IV sedation for PVI as this allows for less patient movement and improved ability to electrically map cardiac tissue with improved catheter contact [13]. Utilizing general anesthesia can improve efficacy rates and provide better patient outcomes in atrial fibrillation ablations.

At the start of atrial fibrillation ablations, a Transesophageal Echocardiogram (TEE) is performed after intubation. Of note, a paralytic is not used after intubation due to observation of the diaphragm. The TEE is utilized to look for thrombus in the Left Atrium as this is a direct contraindication to the procedure. If no thrombus is present, the procedure can continue. An additional preventive measure is esophageal temperature. Esophageal temperature is utilized because of the high frequency/temperature of the catheter used to physically ablate the pathway. This catheter reaches such high temperatures that a major potential complication of an ablation is esophageal injury. Any acute change to the temperature could indicate injury has occurred. Complications in atrial fibrillation ablations include: atrial-esophageal fistula, stroke, tamponade, and pulmonary vein stenosis. These complications were found in roughly 2.9% of the cases [14].

2.1.2 Atrial flutter

Atrial flutter is best known for the saw-tooth pattern seen on EKG. This saw tooth pattern represents the abnormal electrical circuit occurring in the heart and causing rapid beating of the atrium. Atrial flutter is ideal for ablation due to the typical anatomical landmarks found in the right atrium where the ectopic beats are from. Due to this, the success rate of an atrial flutter ablation is 95% [15]. Given the high success rate of catheter ablation of atrial flutter and the difficulty of medically treating this arrhythmia, ablation of atrial flutter has now moved into first-line treatment. Atrial flutter ablations are very similar to atrial fibrillation ablations in terms of anesthetic considerations. TEE still occurs after intubation and no paralytic is used after initial intubation to determine diaphragm status. Additionally, an esophageal temperature catheter is placed as atrial flutter ablations have a similar risk of esophageal injury due to high temperature/frequency being used. Other complications of atrial flutter ablations are in line with atrial fibrillation ablations including stroke, tamponade, and vascular complications.

2.1.3 SVT

Paroxysmal SVT is broken down into pathway mediated tachycardia, AV nodal reentrant tachycardia and focal atrial tachycardia [10]. Pathway mediated tachycardias and AV nodal re-entrant tachycardia are disorders of impulse conduction, while focal atrial tachycardia is caused by a trigger, re-entry, or abnormal automaticity [16]. Typically, patients can present with a multitude of symptoms including palpitations, shortness of breath, and decreased exercise tolerance. The pathway of treatment for these patients starts with calcium/beta blockers or class Ic/III anti-arrhythmic agents. Depending on patient preference and success of medical therapy, catheter ablation can also be performed [17]. The focus of this type of ablation is the pre-mapping which finds the specific ectopic location or abnormal pathway in the atria and/or ventricles. This site is then ablated using radiofrequency energy or cryo-therapy with
an 85–90% success rate for cessation/cure of the arrhythmia [10]. SVT ablations differ in anesthetic management. These ablations do not require intubations as the goal for this procedure is to have the patient follow commands during the procedure. During the catheter placement and ablation, the patient may be sedated more, but after these instances the patient should be able to follow commands. The overall goal is to have the patient alternate between an asleep-awake-asleep cycle with the overall goal being a dissociated patient.

Arterial lines (A-lines) in EP ablations are on a case-by-case basis. If the patient has medications that require an A-line then one will be placed. One consideration that holds true is if the patient has an ejection fraction (EF) <35%, an A-line should be placed. This A-line will allow the possibility of acute intervention if needed. Additionally, for all ablations post-operative management is similar. Patients should lay supine for 4–6 hours to prevent bleeding from the catheter sites with a pressure dressing applied. After this period of time, the patient is typically discharged to the cardiac floor for further monitoring (Table 1).

2.2 Implantable devices

2.2.1 Pacemakers

The traditional pacemaker provides an external electrical stimulus by which myocytes may be depolarized, eliciting contraction of the heart muscle (Figure 1) [18]. Pacemakers function when the intrinsic pacing system of the heart fails to pace effectively and quickly enough to provide an adequate cardiac output for the patient. Muscle contraction takes place almost instantaneously following electrical impulse through the process of excitation-contraction coupling. The components of the traditional pacemaker include a pulse generator, housing a battery and electrical components, and leads, which project from the device housing into the myocardium to provide the site of impulse delivery [19]. These leads in the modern pacemaker also have the capacity to sense the heart’s native electric activity in specific chambers to determine when the pacemaker should provide the external stimulus, and whether that external stimulus is necessary [19].

There are many indications for the use of conventional pacemakers and these indications continue to expand with new technology. Pacemaker implantation can be considered for patients with sinus node dysfunction, acquired AV nodal conduction and HIS Purkinje pathology, neurocardiogenic syncope, neuromuscular diseases impacting cardiac tissue conduction, and congestive heart failure [19]. Equipment and techniques for pacemaker implant continue to evolve and improve the safety of this procedure but like any invasive procedure there are inherent risks associated with the procedure. Implantation of the actual pacemaker is started with a small (~5 cm)
incision in the upper chest. Then a wire is threaded through the vein and into the heart. This wire connects directly to the pacemaker to generate the electric signal that is required to physically pace the heart. The type of pacemaker as well as indication of the pacemaker will determine the specific chamber(s) where the wire(s) is placed. A common placement for the wire is in the right atrium and can be confirmed via chest x-ray. Prior studies have demonstrated varying complication rates for pacemaker implantation ranging from 3 to 10% [20]. The studies have shown that both patient characteristics and center volumes impact procedural complication rates. The most frequently reported major complication related to pacemaker implants are lead related re-interventions, while hematoma is the most reported minor complication. Other possible complications can include infection, cardiac perforation, pneumothorax, and lead dislodgement [20].

Within the last 10 years, leadless cardiac pacemakers have come onto the scene as a potential alternative option to traditional cardiac pacemakers [21]. These devices were designed to offer a leadless system to avoid many of the short and long-term complications that occur with transvenous pacemaker leads. A leadless device is much smaller than a traditional pacemaker in size and these devices will continue to miniaturize. The leadless device features electronics, a lithium battery, and electrodes. Uniquely from a conventional pacemaker, however, is the fact that the device housing includes both the pulse generator and the electrode which delivers that impulse to the cardiac tissue. An attachment end is used to screw in or attach via prongs into the endocardium. Different from the traditional pacemaker, the leadless model is installed via a sheath beginning in the femoral vein and extending up to the right ventricle which can be seen on chest x-ray [21].

While leadless pacemakers share some features of transvenous pacemakers, they are much more recent in their development, and are not able to be utilized for the full
range of indications of transvenous pacemakers. Leadless pacemakers are rate adaptive and may modify pacing upon detecting a patient exercising. These devices have a battery life of approximately 10 years and are externally programmable, a feature shared with traditional pacemaker devices. The first leadless cardiac pacemaker was a ventricular only system: it senses and acts on a ventricle, has inhibitory activity, and features a rate response function. A newer pacemaker, the Medtronic Micra AV is able to sense the atria and pace the ventricle for patients in sinus rhythm with heart block (Figure 2) [22]. This newer technology, which can be seen on chest x-ray, indicates the advancement of the leadless pacemaker and the capability it has (Figure 3) [23].

Leadless pacemakers have a growing list of indications for use as the technology further evolves. Indications include permanent atrial fibrillation with AV block,

Figure 2.
Micra leadless pacemaker [Metropolitan Heart and Vascular Institute].

Figure 3.
Leadless pacemaker on chest X-ray (Khader et al. [23]).
second- or third-degree block in patients with normal sinus rhythm, and sinus bradycardia [24]. As uses for the leadless pacemaker expand, so does understanding of the possible complications of this device. Major complications include cardiac injury, complications at the site of entry in the groin, thromboembolism, presyncope, syncope, cardiac failure, and acute myocardial infarction, among others. Classically, the most reported of these major complications are problems at the site of catheter entry as well as perforation of the myocardium, which differs from the higher rates of electrode dislodgement, site infections, and lead fractures seen in transvenous pacemakers [21, 25]. In a study on a specific model of leadless device, the micra transcatheter pacing study, complications were reported from the 12-months post-implantation of the leadless device [26]. This study involved 745 patients at 56 centers in 19 different countries and compared prospective data on the Micra leadless system with historical data on transvenous pacemakers. Overall, the leadless system had a lower risk of major complications by a difference of 48% mostly related to the reduction in system revision. Last, no major infections have been attributed to the Micra leadless device at 12 months, which is encouraging given the infection risk seen with transvenous pacemakers [26].

As with any new technology, many opportunities exist for improvement of the leadless pacemaker. For one, improving safety of the device, and in particular, the installation process, would further set the leadless pacemaker apart from its transvenous counterpart. Specifically, modifying how the device attaches into the myocardium is one such way that has been suggested to reduce perforation risk. In addition, development of improved battery lifespan or a charging system for the battery within the pacemaker will allow for a longer device usage with fewer repeat procedures [27]. Aside from improvements in safety, the uses for the leadless pacemaker may also continue to expand with time. In fact, efforts are already underway to develop an atrial leadless pacemaker in addition to dual chamber pacing, two areas which can increase the number of patients who may benefit from such a device [28].

2.2.2 Implantable cardioverter-defibrillator

Conventional transvenous implantable cardioverter defibrillators (ICDs) consist of similar components to a transvenous pacemaker: a battery, a pulse generator, and leads, which ultimately provide a pathway for shock delivery to cardiac tissue [29]. To deliver a shock, charge first accumulates within the capacitor of the device before being expelled through the leads to reach the myocardium. In addition to delivering a shock in instances of ventricular arrhythmia, modern ICDs feature pacing activity similarly to pacemakers. Therapies for arrhythmia delivered by ICDs come in multiple forms, with synchronized versus asynchronous shocks as well as overdrive pacing. Synchronized and asynchronous shocks work to terminate abnormal rhythms, such as ventricular fibrillation and ventricular tachycardia, through electrical cardioversion. In contrast, overdrive pacing can be utilized in ventricular tachycardia, where the ICD transiently delivers pacing at a rate above the rate of tachycardia to cease the arrhythmia. These ICD devices come in single chamber and dual chamber systems, with dual chamber systems able to discriminate between atrial and ventricular arrhythmias and provide pacing output to both chambers [29]. Finally, cardiac resynchronization therapy defibrillators can be used to simultaneously pace the right and left ventricle in patients with heart failure believed to be exacerbated by conduction system disease.

Indications for an ICD include use as primary and secondary prevention. Primary prevention involves placing a defibrillator to prevent cardiac arrest in patients with
known cardiac conditions that place them at increased risk for lethal ventricular arrhythmias. These conditions include but are not limited to: ischemic and non-ischemic cardiomyopathy with left ventricular ejection fraction <35%, long QT syndrome, Brugada syndrome, hypertrophic cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy [30]. Secondary prevention indications include those patients who have already suffered a cardiac arrest from ventricular tachycardia or ventricle fibrillation and those patients with sustained ventricular tachycardia in the setting of structural heart disease [30]. Regarding the risks of transvenous ICDs, there are many overlaps with complications seen in transvenous pacemakers. Common risks of conventional ICD devices include lead-related issues which require revision, localized and systemic infections, cardiac perforation, and hematoma at the site of implantation [20].

Similarly, to the recent rise in leadless pacemakers as a potential alternative to transvenous pacemakers, subcutaneous ICD (S-ICD) devices have been recently developed to rival or improve upon transvenous ICD (TV-ICD) systems. These S-ICD devices are implanted within the subcutaneous tissue typically on the left side allowing for shock delivery of 80 Joules through tissue adjacent to the heart as opposed to leads directly projecting into the heart chambers (Figures 4 and 5) [31, 32]. This difference in function results in a different profile of complications; S-ICD complications include pocket infections and device erosion [33]. Conversely, complications of transvenous ICDs are predominantly due to its lead system and include perforation of cardiac tissue, tamponade, pneumothorax, and lead repositioning [34]. Of note, S-ICD devices may be used for many of the same indications of TV-ICDs, such as primary or secondary life-threatening arrhythmia prevention or certain patients with congenital or inherited cardiac conditions (including hypertrophic cardiomyopathy, Brugada syndrome, and ischemic and non-ischemic cardiomyopathies, among others) [33]. Therefore, the advent of S-ICDs expands options for patients considering ICD implantation and allows patients and clinicians to work together in determining which risks may be best tolerated in the long term.

Figure 4.
Subcutaneous ICD [CardioNetworks].
2.2.3 Further anesthetic considerations for PM and ICD

Anesthesia for pacemaker and ICD placement traditionally required general anesthesia under the direction of an anesthesiology team. Modern approaches to sedation for device placement have involved use of a lower level of sedation and in some cases occur under a proceduralist directed, nurse administered (PDNA) model. In particular, the placement of traditional transvenous pacemakers and leadless pacemakers now favors this PDNA model to achieve conscious sedation in these patients [35]. However, the role of the anesthesiology team in such a procedure is largely determined by patient characteristics impacting the risk of such a procedure. ICD placement may also favor this PDNA model, due to an increasing push toward conscious sedation in ICD placement procedures. In fact, a conscious sedation model using opiates with benzodiazepines may be more favorable when compared to general anesthesia due to shorter procedure and recovery times as well as cost to patients [36]. In cases where sedation using Propofol is to be used, the risk of hypotension and respiratory depression must be considered. In these cases as well as cases involving deep sedation during device placement, it is recommended that proceduralists consider involvement of anesthesiology [35]. Additionally, differentiating between ICD and pacemakers on chest x-ray is imperative to ensure adequate anesthesiology pre-operative prep. To distinguish a pacemaker vs. ICD on chest x-ray, Pacemakers have small leads (Figure 6a), where ICD’s have thick coiled segments at the end of their leads (Figure 6b) [37].

For patients with an active ICD, special considerations are needed for any additional procedures that these patients go through. For example, a magnet is placed over a patient with an ICD before incision and then removed after the procedure is performed. This magnet turns off the ICD shock function to ensure patient safety throughout the operation. In some cases, the ICD beeps to ensure the shock function has been disabled and will beep again when the magnet is removed. In other cases, a device representative will be present in the room to ensure the device’s shock has been disabled and to interrogate the device as needed. Active pacemaker patients also have...
special considerations before surgery that need to be considered. Device interrogation should be done before and after surgery if the surgery is directly affecting the device or if any complication occurs during the procedure involving the pacemaker. Additionally, similar to ICD’s magnets can be used before surgery to place the pacemaker in asynchronous mode. However, before considering using a magnet for a pacemaker there are several considerations that need to be addressed including the dependency of the pacemaker for the patient, the type of surgery, and is the pacemaker obstructing the surgical field. ICD and pacemaker patients need these special considerations before procedures to ensure the success of the operation.

2.3 Noninvasive and invasive cardiac monitoring for arrhythmias

Before noninvasive cardiac monitoring, many arrhythmias would be missed due to the arrhythmia not occurring at the specific moment the EKG was being taken. Today, various monitors allow clinicians to detect many arrhythmias such as atrial fibrillation, atrial flutter, tachycardia-bradycardia syndrome, junctional rhythms, and many more outside of the office or hospital. Typically, if a patient presents with palpitations, subjective irregular heart rhythm, unexplained syncope, or other cardiac manifestations with a normal EKG; a Holter monitor or ambulatory extended monitor can be utilized. A Holter monitor or ambulatory extended monitor is a wearable device that has electrodes that record EKG’s. The device can be worn between 1 day to 4 weeks but in general does not provide real time data. These devices have the downside of being cumbersome to the patient as they are bulky and limit daily activity (Figure 7) [38].

Mobile telemetry is similar to Holter and event recorders but involves real time monitoring by a data center that can notify a patient or physician immediately of an arrhythmia. An implantable cardiac loop recorder is a small device implanted under the skin that can track rhythm, rate, and even correlation with symptoms of the patient (Figure 8) [39, 40]. Implantation of loop recorders do not require IV sedation. Lidocaine is typically used to numb the area before the 10–15 minute procedure. Loop recorders have a battery life up to 5 years and can store data and transmit the data almost immediately to a monitoring physician [39]. A study in 2007 showed that loop recorders were superior for the diagnosis of an arrhythmia over the conventional treatment method of Holter monitor (24 hours), 4-week random EKG monitoring,
and an EP study [41]. One of the primary uses for loop recorders in the modern era is detection of occult atrial fibrillation in patients with a cryptogenic stroke. Prospective studies have demonstrated that in patients with cryptogenic stroke, when a loop recorder is placed, atrial fibrillation will be discovered in up to 30% over 3 years of monitoring [42]. Loop recorders have shown a significantly higher diagnostic yield than periodic EKG monitoring or 24 and 48 hour Holter monitoring for these patient populations [43]. From a clinical standpoint, if a patient presents to the office with any cardiac manifestations pointing to a serious cardiac arrhythmia that occurs rarely throughout a 12 month period, a loop recorder may be the most cost effective and efficient diagnostic tool.

3. Discussion

Cardiac electrophysiology is an ever-growing field. One of the possible advancements with EP is performing the procedures without fluoroscopy. Fluoroscopy allows the proceduralist to visualize the surgical field for ablations, pacemaker/ICD implantations, etc. The main concern with fluoroscopy is the amount of radiation exposure to the EP lab team. As Low As Reasonably Achievable (ALARA) is an implemented system to reduce radiation exposure in the lab. Certain recommendations utilizing this concept are a certain distance from the table, additional lead shielding, table height, and appropriateness of fluoroscopy [44]. As these measures are actively being done in EP labs, exposure of radiation is still imminent.

Advancements to utilize other imaging in substitution of fluoroscopy could potentially be the future of the EP lab. Imaging such as intracardiac echocardiography, cardiac MRI guidance, and 3D electromapping systems have all been proposed [45]. Using these styles of imaging could produce the same result with a much less radiation exposure risk for not only the patient, but also the physician and their team. Robotic
surgery is also an option as this would eliminate the number of people required to be present in the room. Overall, these advancements are still far away as there needs to be a clear indication that success rate of the procedure nor the patient outcome would not falter, but a fluoroscopy-free EP lab could be the future of electrophysiology.

4. Conclusion

In conclusion, cardiac electrophysiology is an ever-growing field with many advances in recent years. The field itself has an extraordinary amount of depth and conditions that can be treated. Pacemakers, ablations, and ICDs are the forefront of electrophysiology, but the field is actively expanding into cardiac monitoring. The anesthesia management of EP procedures is quite extensive. Atrial fibrillation and Atrial flutter ablations require TEE pre-procedure as well as active esophageal temperature monitoring. SVT ablations do not require intubation, but require an extensive awake-sleep-awake cycle with the overall goal being a dissociated patient to actively monitor the patient during the procedure. ICD/pacemaker anesthesiology practice favors a PDNA model, but each patient is considered on a case-by-case basis. Anesthesiology and electrophysiology work hand in hand to give the best possible care for the patient and to ensure optimal patient outcomes.
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